

# NASA's SPACE ENVIRONMENTS AND EFFECTS (SEE) PROGRAM

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## **Abstract**

The return of the Long Duration Exposure Facility (LDEF) in 1990 brought a wealth of space exposure data on materials, paints, solar cells, adhesives and other data on the many space environments. The effects of the harsh space environments can provide damaging or even disabling effects on a spacecraft, its sub-systems, materials and instruments. In partnership with industry, academia, and other US and international government agencies, the National Aeronautics & Space Administration's (NASA's) Space Environments & Effects (SEE) Program defines the space environments and provides technology development to accommodate or mitigate these harmful environments on the spacecraft. This program (agency-wide in scope but managed at the Marshall Space Flight Center) provides a very comprehensive and focused approach to understanding the space environment. It does this by defining the best techniques for both flight- and ground-based experimentation, updating models which predict both the environments and the environmental effects on spacecraft and ensuring that this information is properly maintained and inserted into spacecraft design programs. This paper will describe the current SEE Program and discuss several current technology development activities associated with the spacecraft charging phenomenon.

## **Introduction**

The SEE Program was formed by NASA in 1993 to support the growing need for the development and maintenance of a preeminent program in space environments and effects technology. This initiative is intended to provide a coordinated national focus for innovative technology development to support design, development and operation of spacecraft systems that will accommodate or mitigate effects due to the presence

of the different space environments. The Program is unique in that it was initiated as a customer-driven and product-oriented endeavor. Considerable effort is made to ensure that the potential industry, academia and government agency users of the products are consulted and made a part of the Program. Today, these users constitute the SEE Program's User Steering Committee and Technical Working Groups. Their assessment, prioritization and technical involvement in the tasks that are performed in the areas of space environment definition and effects calculation form the basis for the SEE Program's activities. These activities are open to the following technical areas:

- Spacecraft Charging
- Ionizing Radiation
- Materials and Processes
- Meteoroids
- Contamination
- Electromagnetic Effects

The User Steering Committee and Technical Working Groups are comprised of experts from government, industry and academia from all over the United States. This direct involvement of potential customers and technical experts ensures that SEE Program sponsored products are made available in a timely manner to those most concerned with the information, i.e. spacecraft designers and operators.<sup>1</sup> Examples of such sponsored products include:

- Standard ground test protocols are developed and validated to reduce spacecraft risk and the design costs associated with independently establishing a protocol for each mission or design program.
- Paints and coatings are developed and validated to accommodate or mitigate on-orbit effects.

- Data are collected from operating spacecraft and archived so they can be used in future spacecraft designs.
- Engineering design analysis tools (models and databases) are developed or updated using science definitions of the space environment to reduce spacecraft design costs.
- Test facilities that more accurately simulate the on-orbit environment are developed and compared with results from existing facilities so that spacecraft performance can be more accurately predicted.
- On-orbit engineering instruments to measure either the environment or spacecraft performance in the environment are developed, validated, and made available for use by missions.
- Flight experiments are developed and operated to assess space environment effects, to enable routine operation in new segments of the environment (such as middle-Earth orbit, MEO) for costs similar to those for low-Earth orbit (LEO) operations, and to validate ground test protocols and design guidelines.<sup>2</sup>

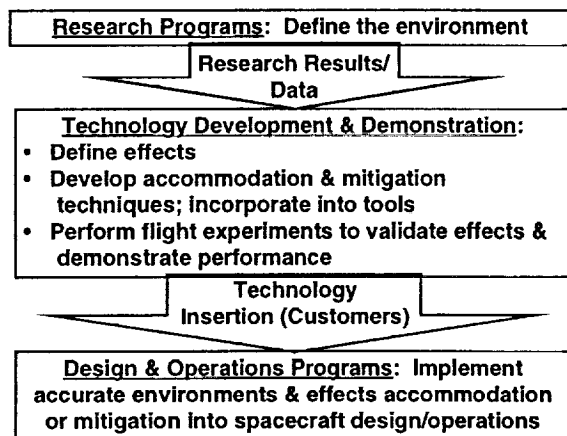


Figure 1. Schematic of SEE Program's Goals

#### Current Technology Development Activities Associated with Spacecraft Charging

The SEE Program's current technology development activities are governed by the US Government's technology export control regulations. Our technology products are developed mainly for US government, industry and academia customers. However, in certain circumstances, foreign organizations and countries are eligible to receive our products, provided they have a valid Technology Transfer Agreement with NASA Headquarters or the United States Department of State. But since NASA and the SEE Program are legally barred

from competing with US industry, eligible foreign entities must also have a legitimate, compelling reason to obtain a requested product. It is not the SEE Program's intention to 'tease' anyone with a description of a technology product that many cannot obtain, but we recognize that enough eligible organizations, many from the US, attend international functions such that it warrants us discussing these products here. Also, due to the ever changing global political climate, new opportunities may suddenly arise which necessitate relationships and Technology Transfer Agreements with foreign customers.

However, the SEE Program is allowed to exchange data and participate in other external collaborations with foreign entities, once again through Technology Transfer Agreements. More information about SEE Program/US export control regulations may be obtained by contacting the author.

Many of the following technology development products will be presented in separate, dedicated presentations at this conference.

#### NASCAP-2K

The NASA/Air Force Spacecraft Charging Analysis Program (NASCAP-2K) is a collaborative effort between the SEE Program, US Air Force Research Lab at Hanscom Air Force Base and the Maxwell Operation of Science Applications International Organization (SAIC), formerly Maxwell Technologies. It is a five-year, comprehensive effort to modernize and update the currently used NASCAP charging analysis code, which is actually three separate codes: NASCAP LEO, GEO and POLAR. This new code will combine all three older codes into one new, revised, comprehensive design tool that can provide detailed and complex charging analyses. It will also make use of the charging algorithms from the US Air Force's Dynamic Plasma Analysis Code (DynaPAC), contain an enhanced materials properties database with never-before-included materials properties, deep dielectric charging analysis capabilities, a dedicated objection definition toolkit and a robust graphical user interface that will provide easy-to-use operation.

NASCAP-2K is an ideal match for today's computers and their large, faster memories, extremely fast processors, and sophisticated graphics capabilities. It will run approximately 100 times faster in a true interactive mode instead of the slower NASCAP batch mode.<sup>3</sup>

The SEE Program is funding several products in this task. One of them is the development of the Object Toolkit (OTk), which includes a spacecraft component database, spacecraft assembler, an on-line tutorial, and robust graphical user interface, all of which will provide a greatly improved geometrical definition capability.

In addition, the SEE Program, in association with a current contract with Utah State University, is providing NASCAP-2K with an enhanced materials properties database that will include new materials not currently available in the old NASCAP codes as well as updated properties to those materials already provided in the old database.

A beta version of NASCAP-2K is scheduled for release in mid 2001 and will contain algorithms for the Geosynchronous orbit. The final release version is tentatively scheduled for distribution approximately six months to one year later. Subsequent versions of NASCAP-2K will contain algorithms for low-Earth and polar orbits as well as previously scheduled code enhancements. NASCAP-2K is Microsoft Windows, Linux and UNIX compatible and uses the Fortran/C, Java and C++ programming languages.

Due to US Government export control regulations, and internal agreements between NASA and AFRL, NASCAP-2K will be available only to US government, industry and academia.

### Interactive Spacecraft Charging Handbook

As a companion to NASCAP-2K, the SEE Program also offers, again in association with the Maxwell Operation of SAIC, the *Interactive Spacecraft Charging Handbook* which is a spacecraft charging analysis tool to be used for preliminary design and analysis.

This design tool offers:

- Updated spacecraft charging guidelines
- Definition of the Geosynchronous environment (Maxwellian or double Maxwellian) and trapped radiation environments (using AP-8/AE-8 models)
- Spacecraft materials selection capability with eight materials included with the Handbook or the ability to add your own custom materials
- Surface charging analysis for single material, multi-material or 3-D material surfaces

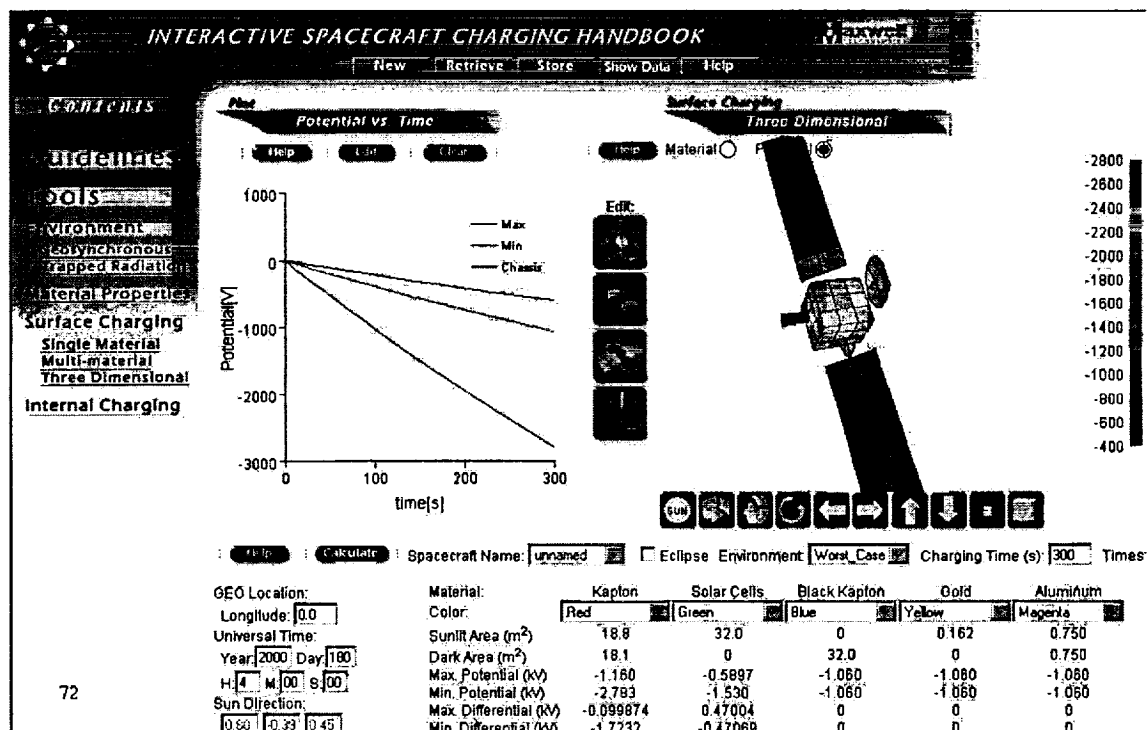


Figure 2. Example Page From Interactive Spacecraft Charging Handbook

- Internal (deep dielectric) charging analysis
- Auroral charging analysis
- Graphing and data export capabilities
- Spacecraft object definition with zoom and rotation capabilities
- On-line help features

This tool was designed for quick, "back-of-the-envelope" calculations and analyses while performing *preliminary* design. And one need not be a spacecraft charging expert in order to use this tool.

The Handbook is multi-platform and can be run on the Microsoft Windows (95 and higher) and Macintosh (OS 7.5 and higher) operating systems. It is browser-based and will work with Microsoft Internet Explorer 4.0 or higher and Netscape Navigator 4.0 or higher, using an 800 x 600 pixel desktop minimum.<sup>4</sup>

Due to US Government export control regulations, the Interactive Spacecraft Charging Handbook is available only to US government, industry and academia.

#### Electronic Properties Of Materials Applicable To Spacecraft Charging

The current NASCAP codes in use today, NASCAP LEO, GEO and POLAR, are inadequate by today's standards, and unfortunately, are the best codes available right now. The original NASCAP codes were written in the late 1970's and released in the early 1980's. Many things have changed since these codes were first released:

- Spacecraft designs have changed
- Spacecraft operating voltages have greatly increased
- New materials have been developed and are in use
- Testing techniques have greatly improved
- An understanding of the physics behind spacecraft charging is much greater

Since the original NASCAP materials database contains only nine materials, the SEE Program, in cooperation with Utah State University, has identified nearly 63 materials that are either in use today or provide a promising future use in tomorrow's spacecraft designs. Many of these materials have never undergone laboratory testing to measure their electrical properties applicable to spacecraft charging. Utah State University is investigating these material properties, especially looking at the secondary and backscattered electron total yields from electron-induced, ion-induced and photon-induced incident energies. This task also includes

investigating yields as a function of environment-induced surface degradation and contamination and surface characterization.<sup>5</sup> Conductors, insulators and spacecraft specific materials are to be tested. The data from this investigation will be incorporated into the original NASCAP materials database as well as be included in the new NASCAP-2K materials database.

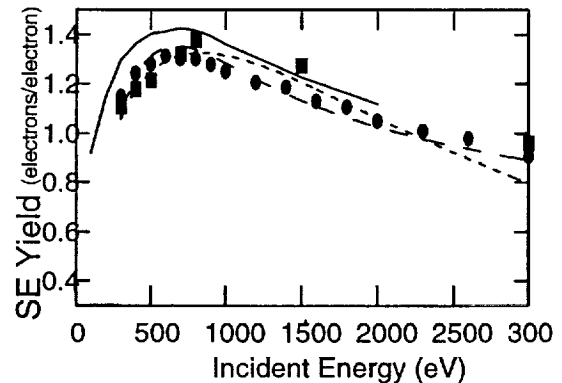


Figure 3. Example of Experimental Results of Secondary Electron Emission of Gold (Au)

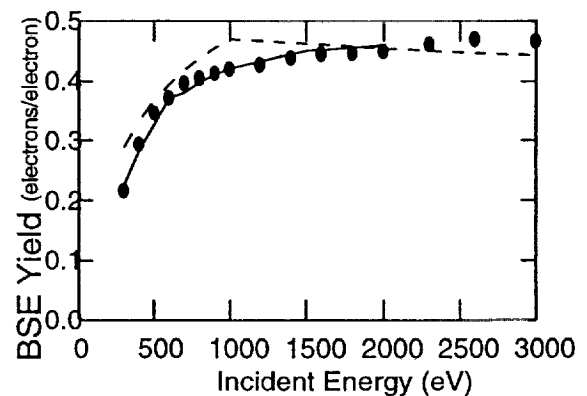


Figure 4. Example of Experimental Results of Backscattered Electron Emission of Gold (Au)

Data from this task meets all US Government export control regulations and is eligible for potential export to interested foreign organizations that have a valid Technology Transfer Agreement with NASA Headquarters in Washington, D.C. The SEE Program is open to mutually beneficial collaborations regarding the use of this data.

#### Tests And Guidelines For Spacecraft Cable Charging

Spacecraft electric cables have been shown to be a major source of spacecraft anomalies. This task, in cooperation with NASA's Jet Propulsion Laboratory (JPL), provided

quantitative data for charging and discharging of spacecraft cables under high-energy electron irradiation typical of Earth's and Jupiter's magnetospheres. Evidence indicates that a significant portion of spacecraft anomalies that occur in the electron radiation belts are caused by discharges on irradiated electric cables. No design guidelines currently exist that tell one how an untested cable will respond or how any cable will respond if small changes are made to the cable or to the radiation environment.<sup>6</sup>

This investigation developed quantitative data and design recommendations for charging and discharging of spacecraft insulators under high-energy electron irradiation. Existing published and unpublished test results were summarized and new data was obtained for untested structures. Design rules were developed to predict the effects of changing both the cable and detailed structure including:

- Insulation thicknesses
- Wire size
- Insulation pinholes
- Applied voltage
- Over-wrap thicknesses
- Shield thicknesses
- Wire spacing
- Leaky coatings
- Leaky dielectrics

Electrons from 5 keV through 1.5 MeV were used for testing. Mitigation techniques to prevent discharges were theoretically available and were developed and proof-tested. Quantitative measurements of pulse magnitudes and frequency of occurrence [A. R. Frederickson, "Method for Estimating Spontaneous Pulse Rate for Insulators Inside Spacecraft," IEEE Trans. Nuc. Sci. 43, 2778-82] were tabulated so that one may design around a pulsing cable if one so desires. Radiation test methods were also formalized for more quickly evaluating future materials and cables. Antennas and lightly shielded circuit boards are also major contributors to charging and discharging events. Therefore, this task also addressed the issue of pulse size generated near sensitive circuits.<sup>7</sup>

Data from this task and future testing activities will be used to formulate a set of tailored design guidelines and methodologies, test techniques, guidelines for parts selection and mitigation techniques to help alleviate spacecraft cable charging. This publication will be expanded for inclusion of future test results, materials and spacecraft components.

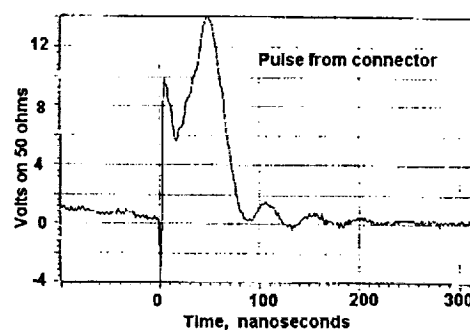


Figure 5. Example of Pulse From Connector

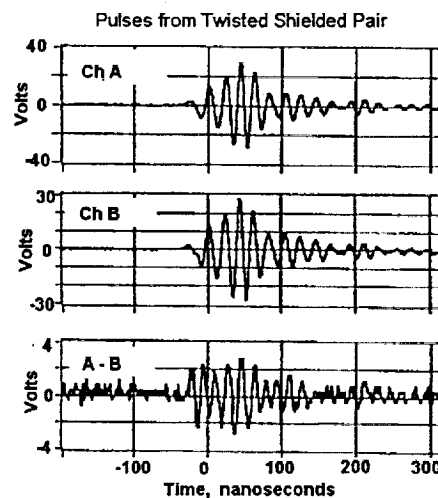


Figure 6. Example of Pulses From Circuit Boards Or Other Planar Insulators

Data from this task meets all US Government export control regulations and is available from the SEE Program for distribution as a hardcopy publication. Interested parties may contact the author or the SEE Program's website at <http://see.msfc.nasa.gov> for more information.

### Living With A Star Program

The Living With a Star Program is a new NASA initiative designed to study the interaction between the Sun and Earth and how this interaction affects all human life and technology. This program is a bold new concept that will bridge the science, engineering and applications communities.

Within the Living With a Star Program lies the Space Environments Testbed (SET). Currently in the formulation stage, this testbed is designed to complete the transition from science to applications with the

objective of improving the engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design and operations.<sup>8</sup> Areas of SET interest that are applicable to spacecraft charging include:

- Plasma environment to characterize surface charging
- Trapped proton and electron environments
- Transient protons and heavy ions

The SEE Program's role in SET is still being developed. Obviously, the SEE Program and SET both share a mutual interest in better/more accurate environment definitions, enhanced models and guidelines that better characterize the plasma environment, and better testing and analysis capabilities to ensure a satellite's satisfactory performance in a harsh space environment. The SEE Program is looking forward to our involvement in Living With a Star and is confident that this new program will enable better environment characterizations and robust technology development.

More information about Living With a Star and its objectives, requirements and program formulation can be obtained at <http://www.lws.gsfc.nasa.gov>.

#### Other Publications

The SEE Program offers numerous other publications for distribution, including technical areas other than spacecraft charging such as ionizing radiation, contamination, meteoroids, materials/processes and electromagnetic effects. All these publications may be ordered by visiting the SEE Program website or completing a publication request form available from the author.

#### Summary

NASA's Space Environments and Effects (SEE) Program, in cooperation with its participants, has made significant progress in the area of spacecraft charging since 1993. As this paper illustrates, its participants now reflect a broad interagency, industrial and academic scope. The Program plays an important role as advocate for space environments and effects related technology development and technology demonstrations. The Program's success, however, depends upon the feedback from government, industry and academic programs on their anticipated needs and the value of the Program's products in their spacecraft systems development and operational activities.

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